

The Stunted Outbursts of UU Aquarii Are Likely Mass-transfer Events

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Abstract

We report a time-lapse eclipse mapping analysis of B-band time-series of UU Aqr along a typical stunted outburst in 2002 August. Disc asymmetries rotating in the prograde sense in the eclipse maps are interpreted as a precessing elliptical disc with enhanced emission at periastron. From the disc expansion velocity an $\alpha_{\text{hot}} = 0.2$ is inferred. The outburst starts with a 10-fold increase in uneclipsed light, probably arising in an enhanced disc wind; the disc response is delayed by 2d. The results are inconsistent with the disc instability model and suggest that the stunted outburst of UU Aqr are the response of its viscous accretion disc to enhanced mass-transfer events.

1. Introduction

UU Aqr is a 3.9 h period deeply eclipsing SW Sex novalike with a bright, viscous disc accreting matter onto a $0.67 M_{\odot}$ white dwarf (WD) at a rate of $10^{-9} M_{\odot} \text{yr}^{-1}$ [1]. Spectral eclipse mapping reveals an uneclipsed emission line spectrum responsible for $\simeq 6\%$ of the total B-band flux, probably arising from a vertically-extended chromosphere + disc wind [2]. With a mass ratio $q = 0.3$, the primary Roche lobe of UU Aqr is large enough to allow the accreting matter to expand beyond the 3:1 resonance radius giving rise to an elliptical precessing disc and to superhumps in its light curves [3]. It also shows 0.3 mag brightness modulations on timescales of a few years (probably caused by 20-50% long-term changes in mass transfer rate [4]) as well as recurrent 'stunted' outbursts of ~ 0.6 mag amplitude which last for ~ 5 -7 d [5] (suggested to be caused by thermal-viscous instabilities in its outer and cooler disc regions).

2. Observations and data analysis

Time-series of B-band CCD photometry of UU Aqr were obtained at the 0.6 m telescope of OPD/LNA, in Brazil, during its 2002 August outburst (started by MJD 54293). The observed outburst was the second of a series of 4 consecutive stunted-outbursts recurring at a typical timescale of a month.

Data reduction, light curve extraction and flux calibration procedures are the same as in Baptista & Bortoletto [4]. The data comprise 6 light curves collected along 5 nights, including 4 eclipses. The first two runs frame the rise to outburst maximum but do not cover the eclipse; two consecutive eclipses were observed at outburst maximum, and two others along the declining stages. The depth of the eclipse at outburst maximum is the same as in quiescence, indicating that the extra light is not from the eclipsed accretion disc. Moreover, there is little change in the depth of the eclipse along the decline, indicating that the accretion disc is not the dominant contributor to the observed brightness changes.

The light curves were analyzed with eclipse mapping techniques to solve for a map of the disc surface brightness and for the flux of an additional uneclipsed component in each case.

3. Results and discussion

Light curves and corresponding eclipse maps are shown in Fig. 1. The eclipse maps show an asymmetric brightness distribution with an arc elongated in azimuth in the inner regions of the accretion disc. As the shape of the eclipse changes with time, the resulting asymmetric arc rotates in azimuth in the prograde sense. Because the time interval between consecutive eclipse maps is known, it is possible to measure the rate at which the asymmetry rotates. The rotation rate inferred from the first two eclipse maps (53° change after 3.9 h) is consistent with the orientation of the asymmetry in the following nights and leads to a precession period of $P_p = (1.14 \pm 0.04)$ d.

The observed asymmetry cannot be a blob of gas rotating in a Keplerian orbit around the WD; at that distance from the WD the Keplerian period is only 14 min, and any structure rotating at that speed would lead to a blurred ring of emission in an eclipse map of a ~ 45 min long eclipse. We tentatively interpret the asymmetry as enhanced emission at the periastron of an elliptical precessing disc. The beat between the orbital and precessional periods leads to a predicted superhump period of $P_s = 1.167P_{\text{orb}}$, longer than the superhump period of 1.175 d found by Patterson et al [3].

Radial intensity and brightness temperature distributions were computed from the symmetric component of each eclipse map. Taking the intensity of the outer radius of the disc in quiescence as a reference intensity level, we find that the disc expands towards outburst maximum at a speed $v_{\text{hot}} = +2.0 \text{ km s}^{-1}$, and shrinks during the decline at a speed $v_{\text{cool}} = -0.16 \text{ km s}^{-1}$. From the expansion velocity we infer a viscosity parameter $\alpha_{\text{hot}} = 0.2$.

Along the outburst, the brightness temperatures in the outer disc remain below the critical limit T_{crit} expected for an outbursting disc according to the disc instability model [6]; the major changes in the temperature distribution occur in the disc region already hotter than T_{crit} . Moreover, there is an equivalent critical mass accretion rate \dot{M}_{crit} above which the disc stays in the high viscosity state and there is no more room for disc-instabilities to set in. We find that $\dot{M} > \dot{M}_{\text{crit}}$ holds at every radius in quiescence and along the outburst.

The upper panel of Fig. 2 shows the time evolution of the total flux, the disc flux and the uneclipsed flux along the outburst. The lower panel shows the changes along the outburst of the fractional contribution of the asymmetric sources in the eclipse map and of the uneclipsed light. The rise to outburst maximum is caused by an increase by a factor 10 in the uneclipsed light, which reaches 50% of the total system luminosity at outburst maximum and decays exponentially thereafter. An increase in the luminosity of the mass-donor star by such a factor would result in conspicuous ellipsoidal modulation and secondary eclipses, none of which are observed. This suggests that this uneclipsed light originates in a strongly enhanced disc wind. The accretion disc only starts to increase in brightness at outburst maximum, about two days after outburst onset.

4. Conclusions

It is hard to explain the impressive increase in disc wind emission without any corresponding change in disc brightness in a disc instability scenario – where the outburst should start (and be restricted to) the cooler outer disc regions [6]. The combined results suggest that the ‘stunted’ outbursts of UU Aqr are driven by recurrent, fast (~ 1 d) increases in mass transfer rate from the donor star by a factor of a few.

References

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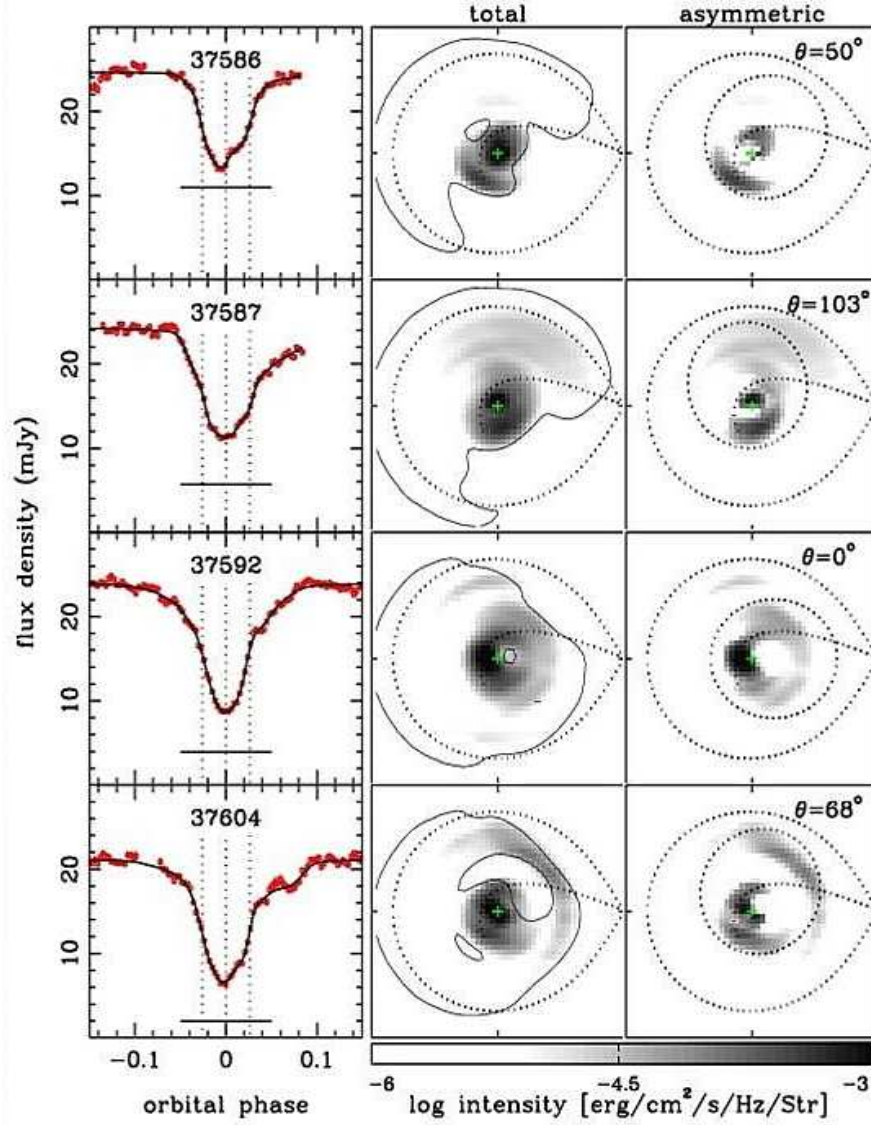


Fig. 1. **Left:** Data (red dots) and model (solid lines) light curves. Vertical dotted lines mark the ingress/egress phases of the WD and mid-eclipse. Horizontal tick marks depict the unclipped flux in each case and labels indicate the eclipse cycle number. **Center:** corresponding eclipse maps in a logarithmic grayscale. Brighter regions are indicated in black; fainter regions in white. Dotted lines show the Roche lobe and the gas stream trajectory; the secondary is to the right of each map and the stars rotate counter-clockwise. A solid contour line is overplotted on each map to indicate the $3\text{-}\sigma$ confidence level region. **Right:** The asymmetric component of the eclipse maps in the center panels. Additional dotted lines depict the orientation of the ellipse of best-fit to the asymmetry in each map. Labels indicate the angle between the semi-major axis of the ellipse and the line joining both stars.

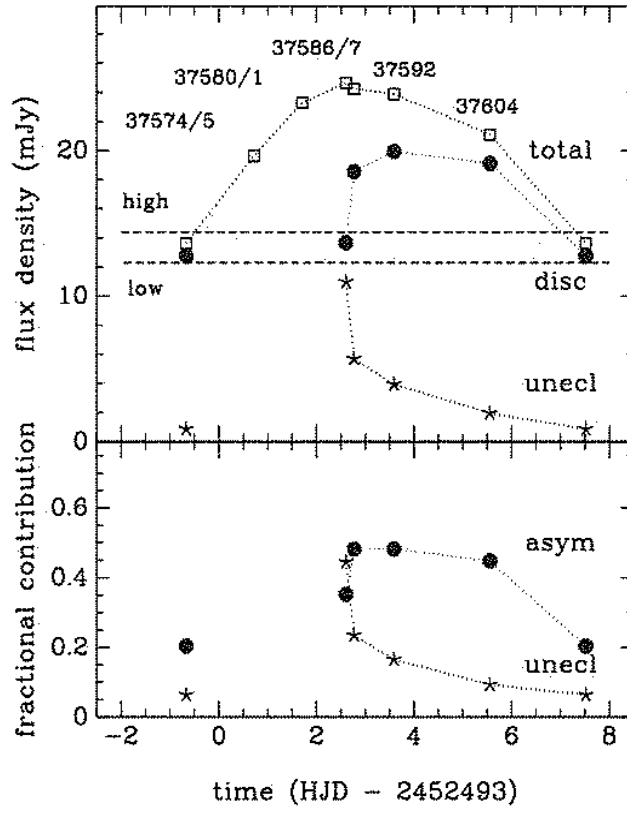


Fig. 2. Upper panel: The time evolution of the total flux, the disc flux and the uneclipsed flux along the outburst. Average values of these quantities for the quiescent state are shown for illustration purposes. Labels indicate the eclipse cycle number. Lower panel: the time evolution of the fractional contribution of the asymmetric sources in the eclipse map and of the uneclipsed light to the total light.

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